

Objective Motion Cueing Criteria for Commercial Transport Simulators

Peter M. T. Zaal, San Jose State University; Jeffery A. Schroeder, Federal Aviation Administration; William W. Chung, Science Applications Internatinoal Corporation

This paper adds data to establish fidelity criteria for the simulator motion system diagnostic test now re- quired during commercial aircraft simulator approval in the United States. Nineteen airline transport pilots flew three tasks under six different motion conditions in an experiment on the NASA Vertical Motion Simula- tor. The motion conditions allowed refinement of the initial fidelity criteria developed in previous experiments. In line with these previous experiments, the motion condition significantly affected (1) false motion cue pilot ratings, and sink rate and longitudinal deviation at touchdown in the approach and landing task, (2) false motion cue pilot ratings, roll deviations, and maximum pitch rate in the stall task, and (3) false motion cue pilot ratings, heading deviation, and pedal reaction time after an engine failure in the take-off task. Combining data from three experiments, significant differences in pilot-vehicle performance were used to define objective motion cueing criteria boundaries. These fidelity boundaries suggest that some hexapod simulators can possibly produce motion cues with improved fidelity in several degrees of freedom.

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Outline

Introduction

Tasks

Motion Conditions

Experiment design

Results

Conclusions



Introduction

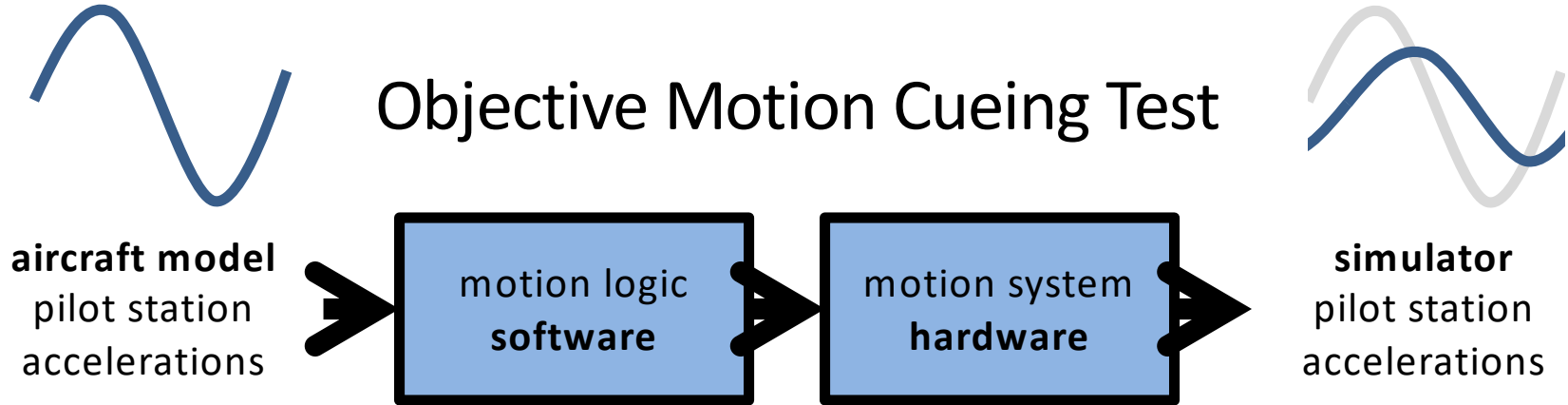
Previously, during a simulator qualification:

- Engineers measured motion hardware
- Pilot inspectors assessed hardware + software

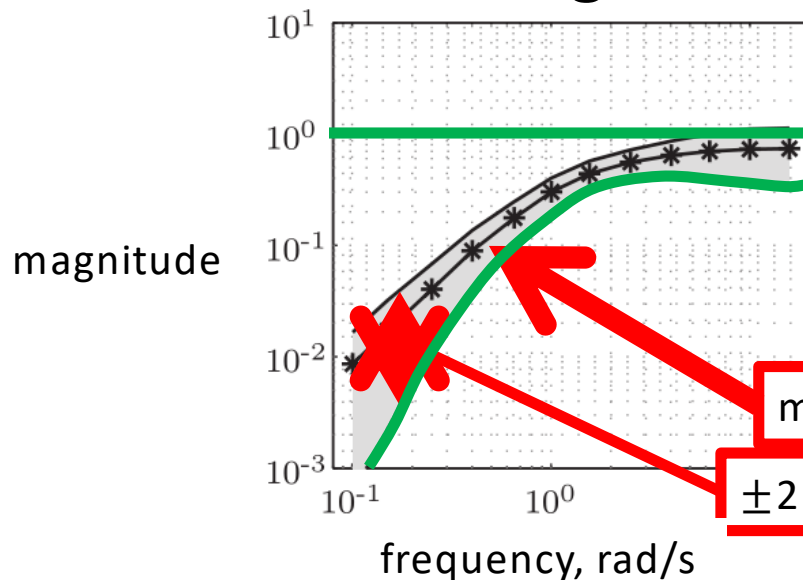
Now:

- FAA part 60 requires an Objective Motion Cueing Test (OMCT) for new devices
 - Currently, no fidelity criteria accompany the test

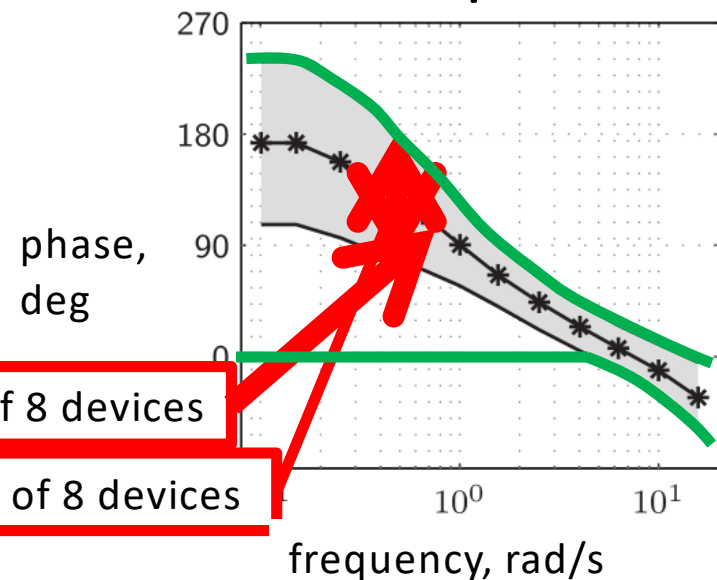
Introduction



Roll magnitude



Roll phase



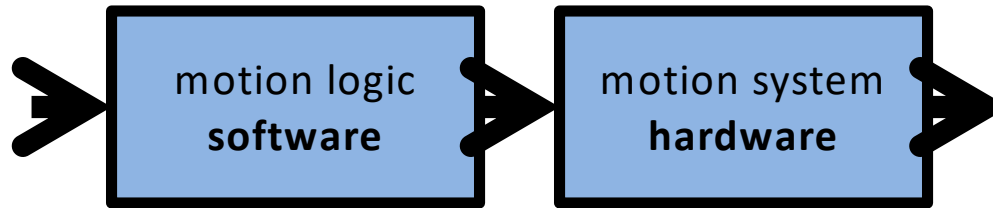
mean of 8 devices

± 2 sigma of 8 devices

Introduction

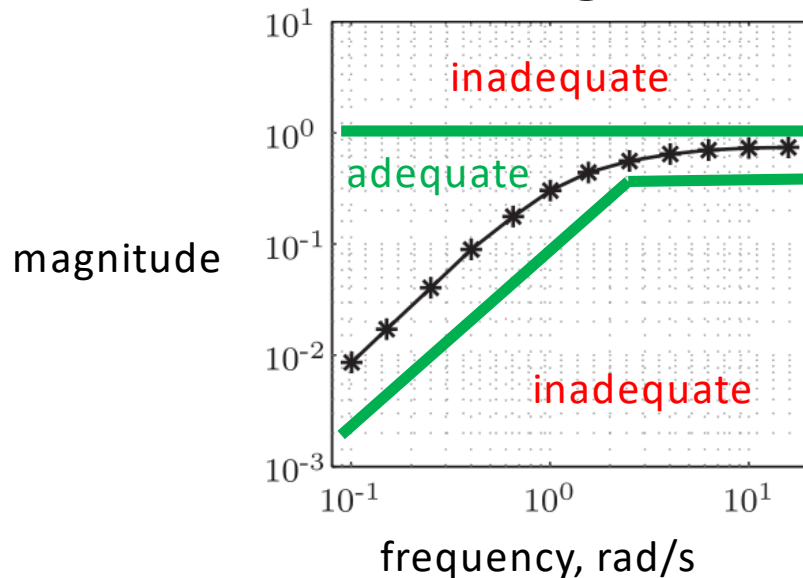
Objective Motion Cueing Test

aircraft model
pilot station
accelerations

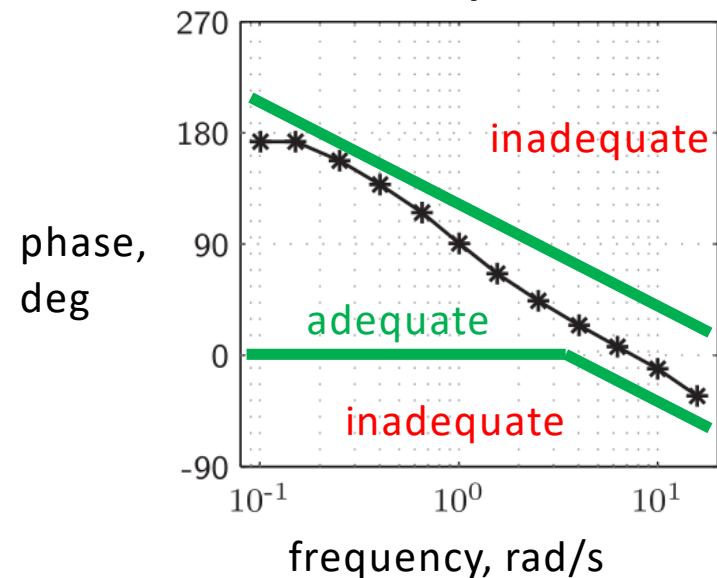


simulator
pilot station
accelerations

Roll magnitude



Roll phase



Introduction

Objective:

Develop fidelity criteria for the Objective Motion Cueing Test for Commercial Transport Simulators

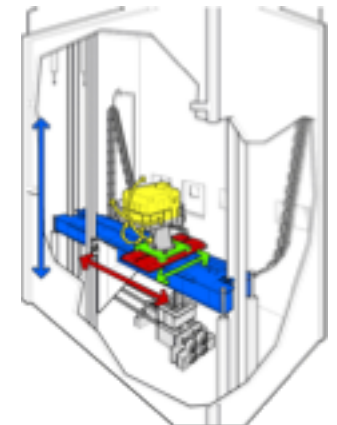
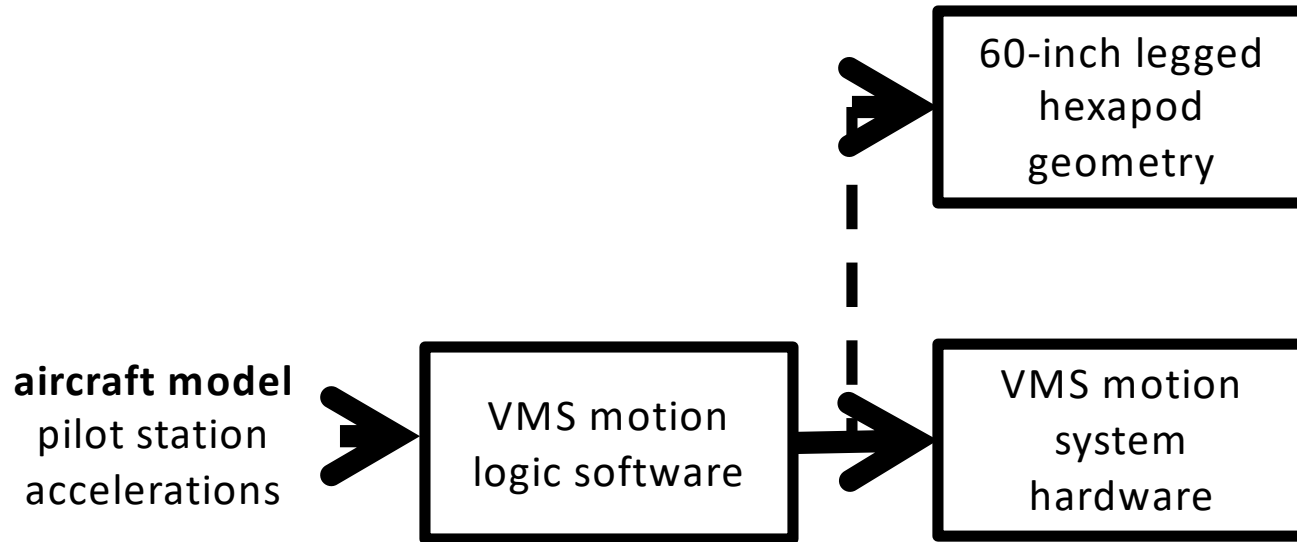
What's new?

- Well-behaved transport aircraft
- Three tasks, 6 new motion configurations
- World's largest motion simulator
- Sufficiently large pilot pool

Tasks

1. Approach and landing with sidestep
2. High-altitude stall recovery
3. Engine out on takeoff

Motion Conditions



Six motion configurations per task:

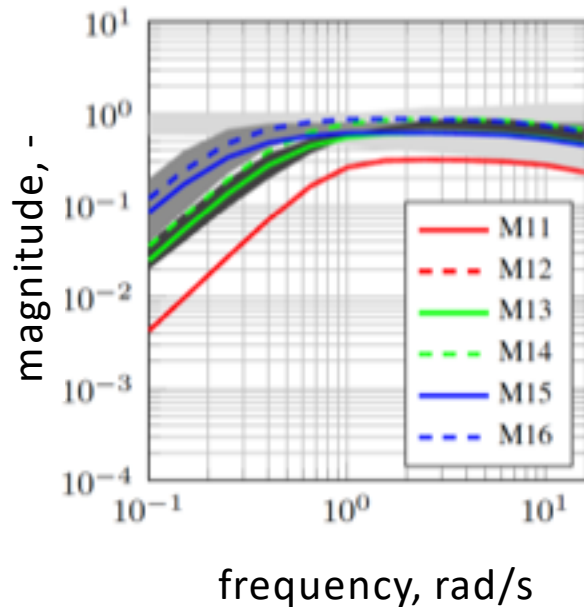
1. Gain/break-frequency tradeoff
2. Compare degrees of freedom
3. False tilt motion cues

Motion Conditions

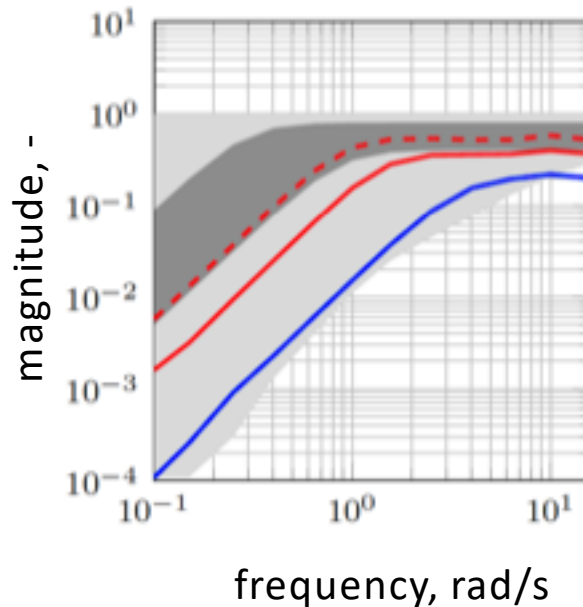
- Sidestep task:
 1. Surge motion -> Tail windshear recovery
 2. Roll motion -> Perceived tilt cues in turns
 3. Pitch and heave -> Landing flare
- Stall task:
 1. Roll motion -> Roll disturbance compensation
 2. Roll motion -> Perceived tilt cues in turn
 3. Pitch and heave -> Secondary stall occurrence
- Takeoff task:
 1. Surge to pitch -> Perceived tilt cues initial acc.
 2. Yaw and sway -> Engine failure compensation

Motion Conditions

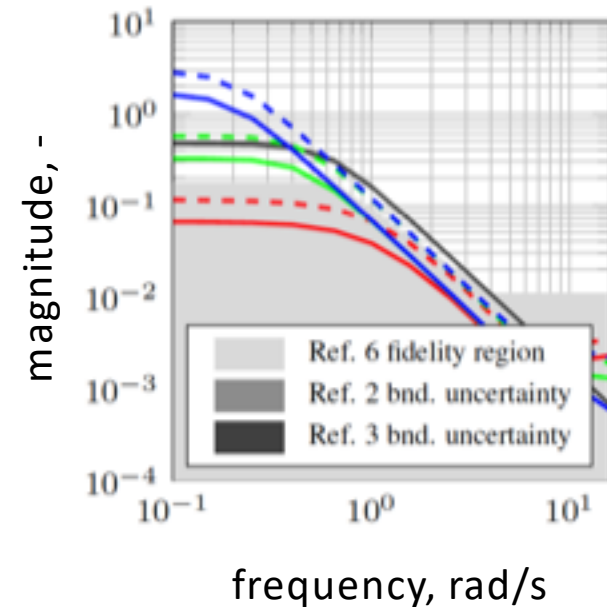
Pitch magnitude



Heave magnitude



Sway to roll
magnitude



Full
VMS
Motion

High
Gain
Hexapod

Low
Gain
Hexapod

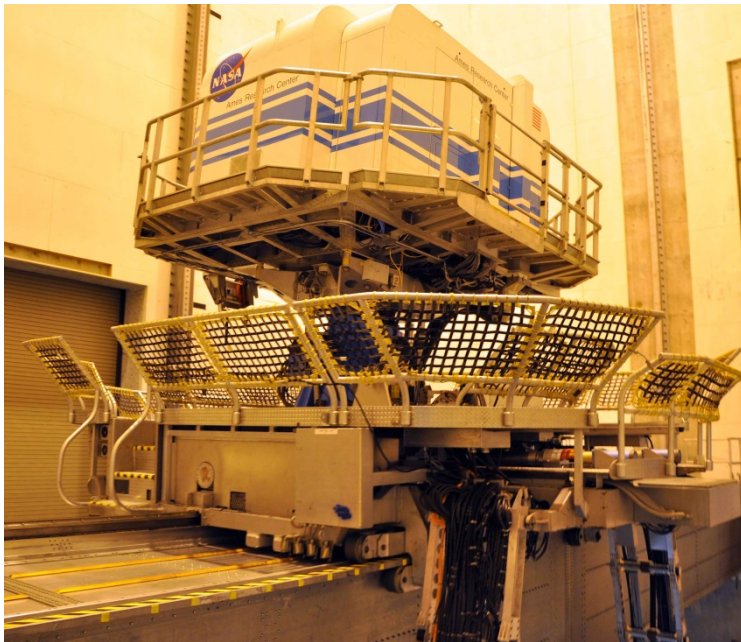
Experiment Design

- 19 airline transport pilots
 - Three challenging flight tasks
 - Six motion configurations per task
 - Six repetitions per task and motion configuration
-
- B757-like aircraft model
 - Cockpit:
side-by-side with
B777-like primary display



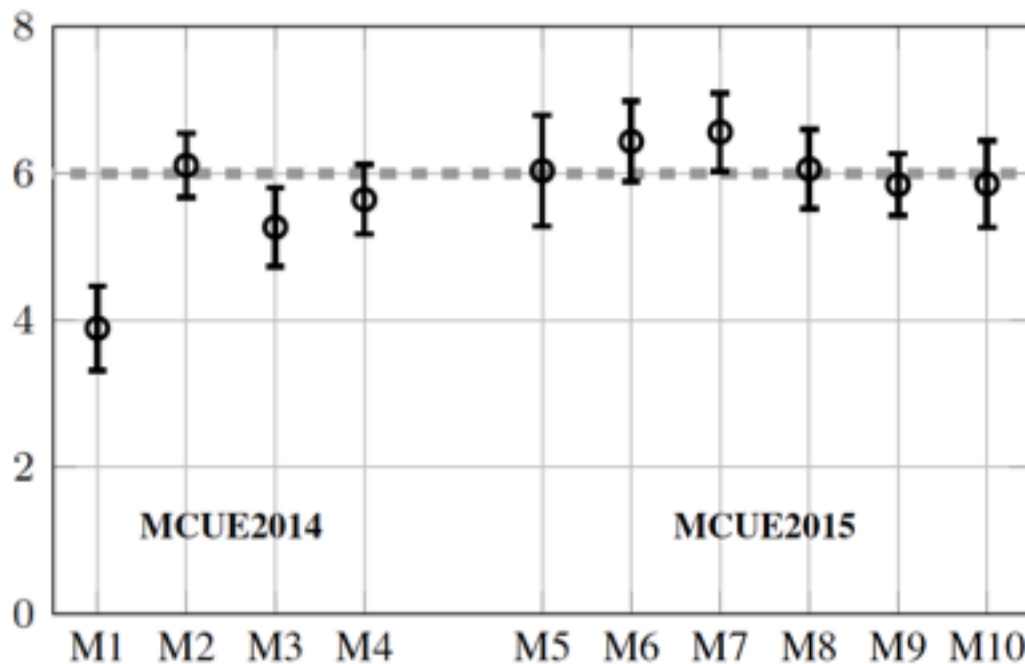
Experiment Design

- Dependent measures:
 - Three subjective ratings of false tilt motion
 - 12 objective task-performance measures

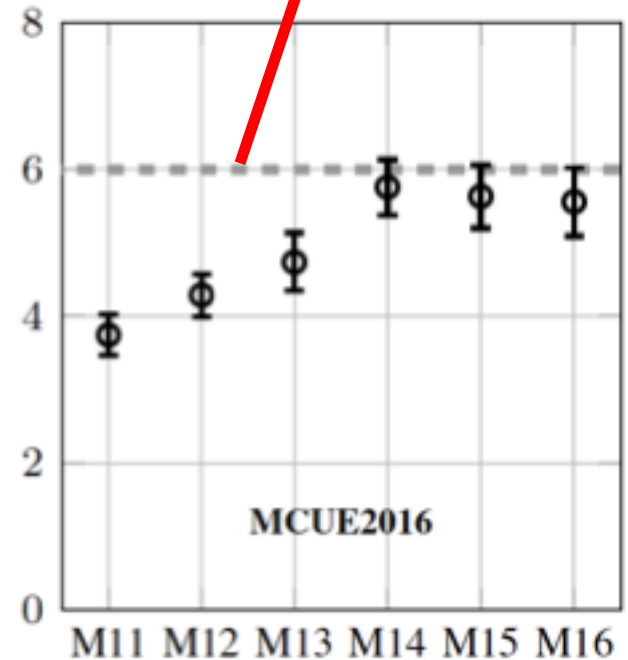


Performance Results Sidestep Task

Sinkrate at Touchdown, ft/s



performance criterion

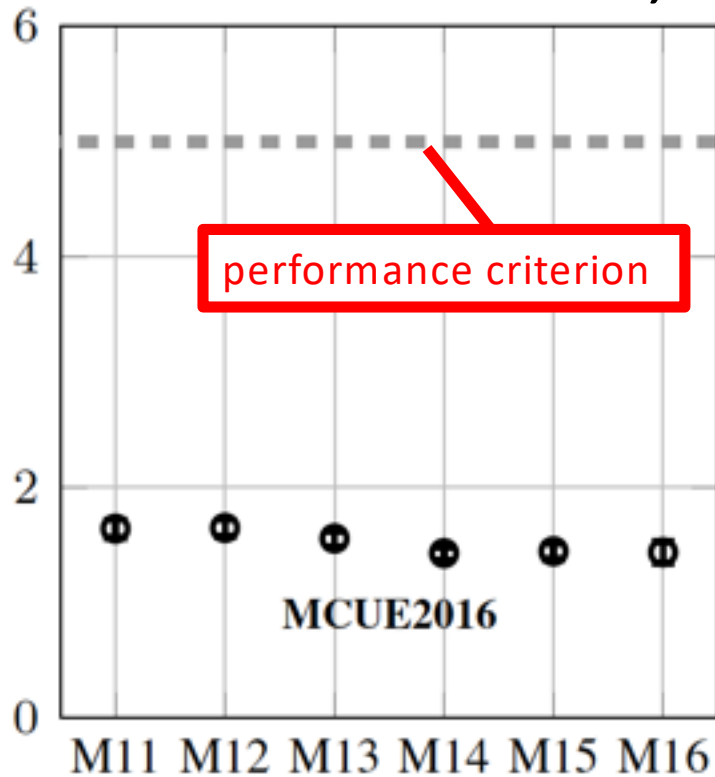


Decreasing heave gain and increasing break frequency

Performance Results

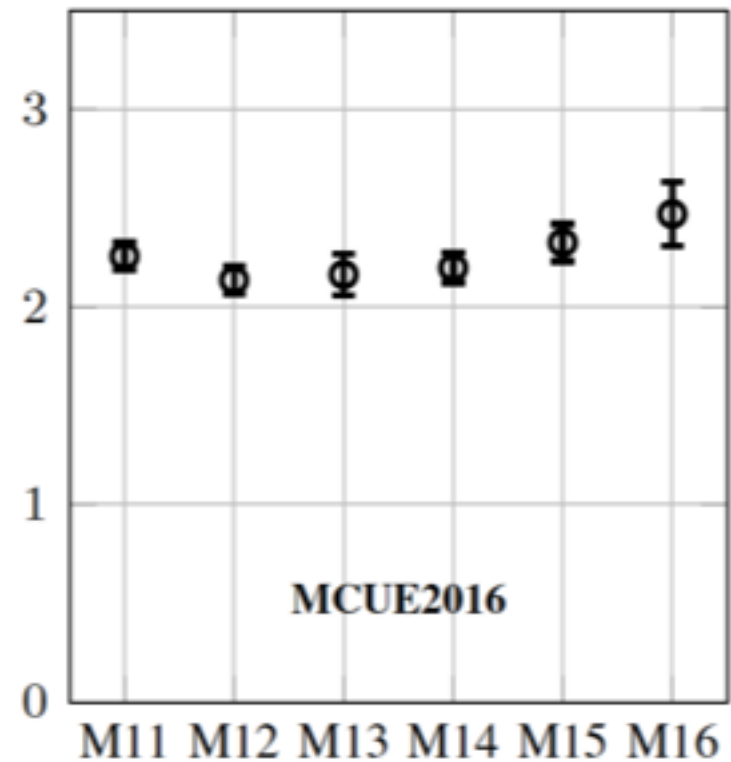
High-Altitude Stall

Roll deviation RMS, deg



Decreasing roll break frequency

Max pitch rate, deg

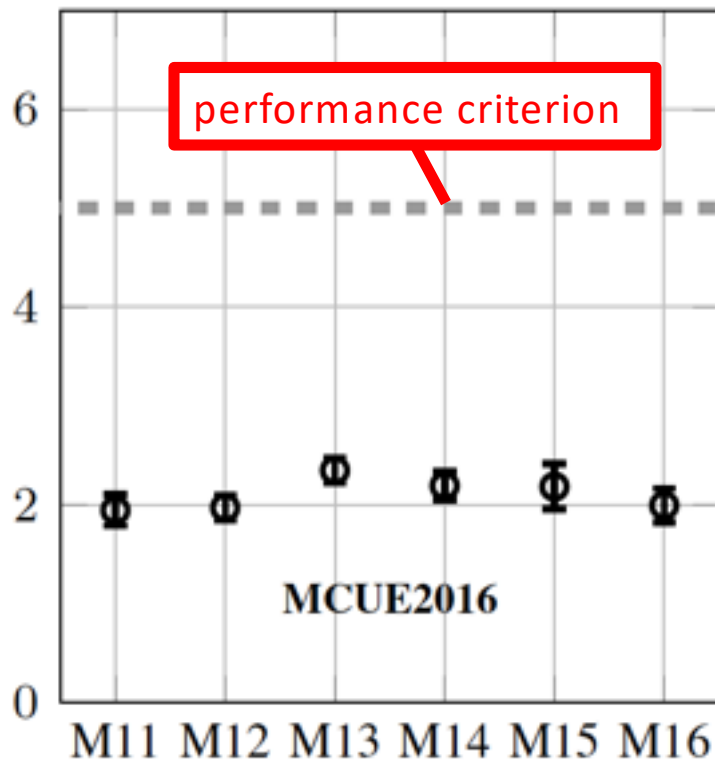


Decreasing heave fidelity and
increasing pitch fidelity

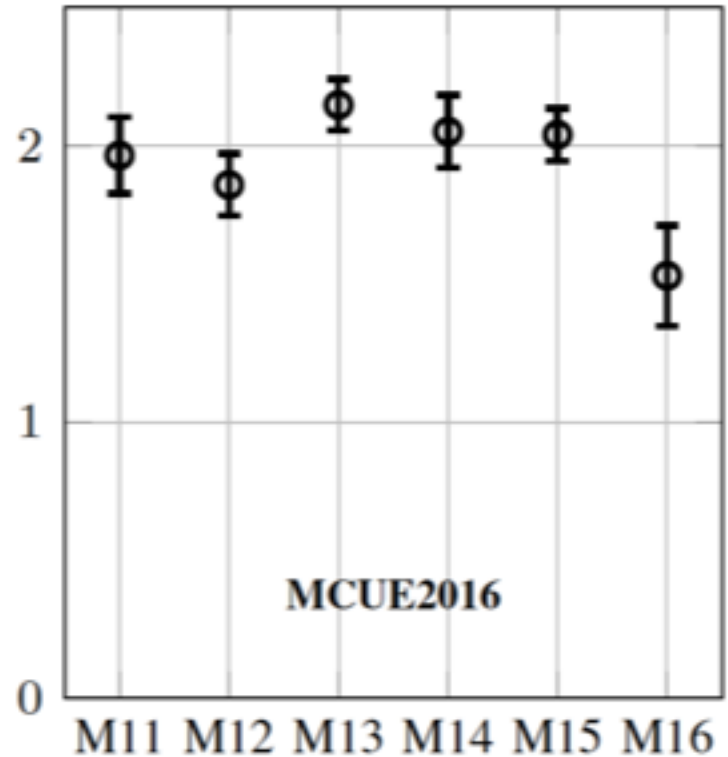
Performance Results

Takeoff Task

Heading deviation RMS, deg



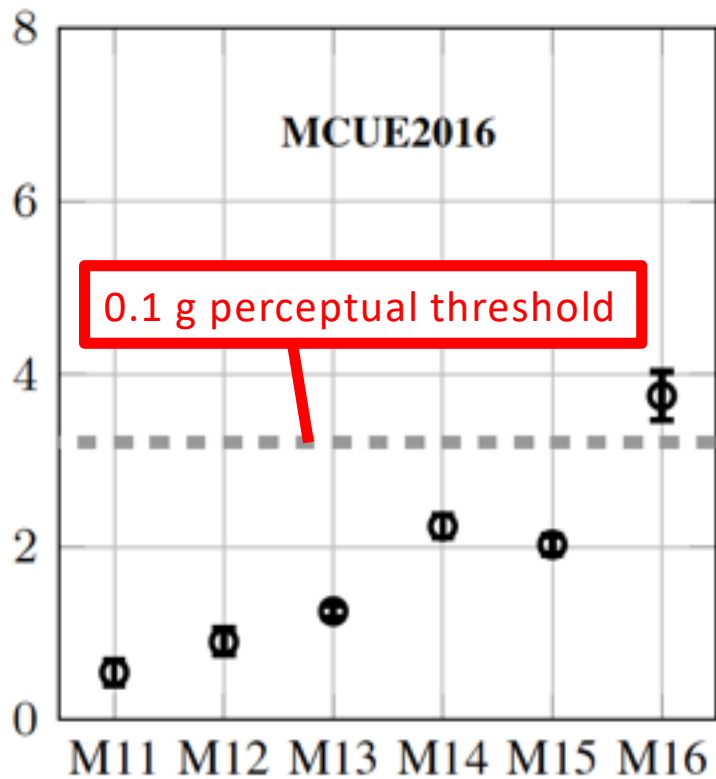
Pedal response time, s



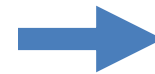
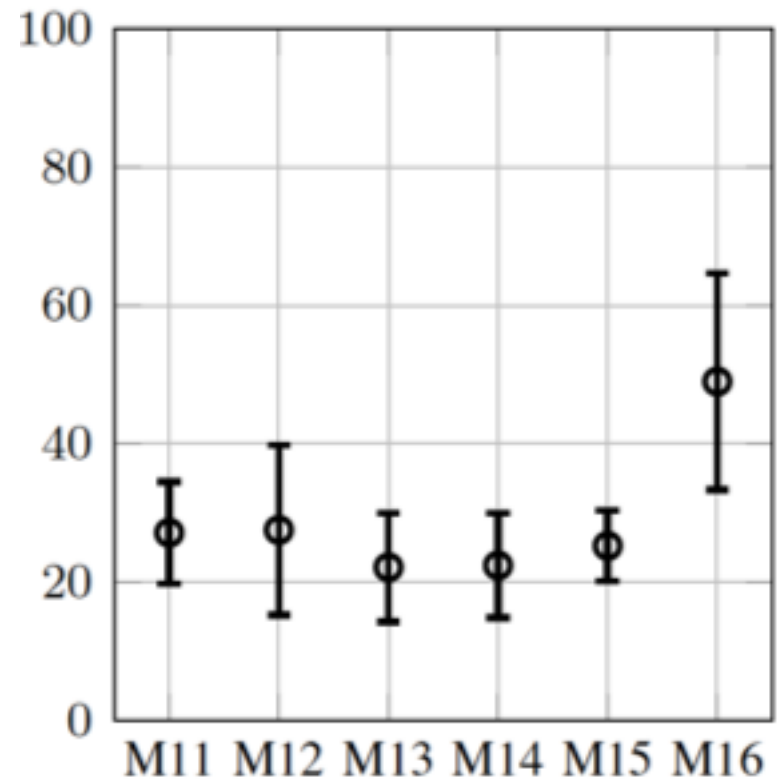
Increasing sway fidelity and decreasing yaw fidelity

Motion Rating Results Sidestep Task

Maximum lateral tilt cue, ft/s^2



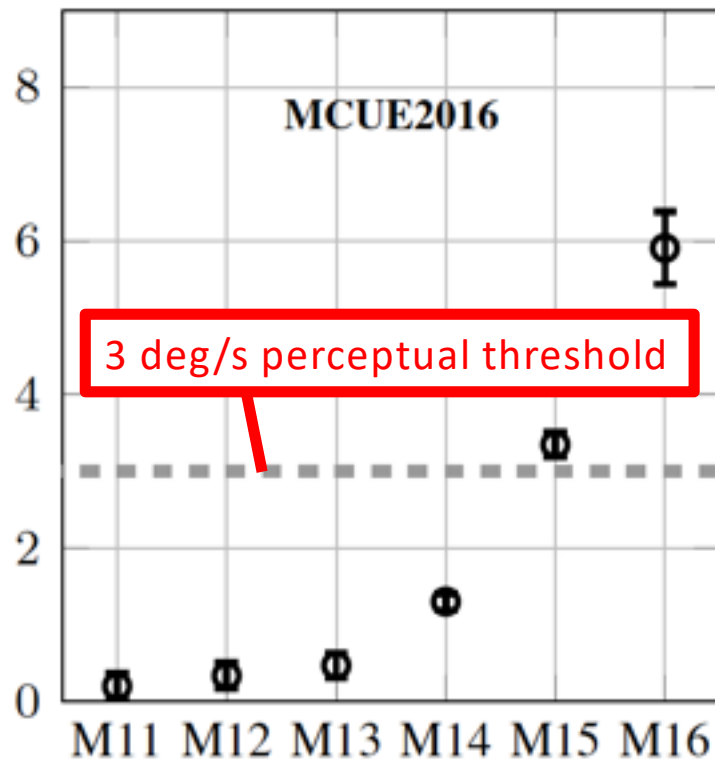
False motion cue rating, %



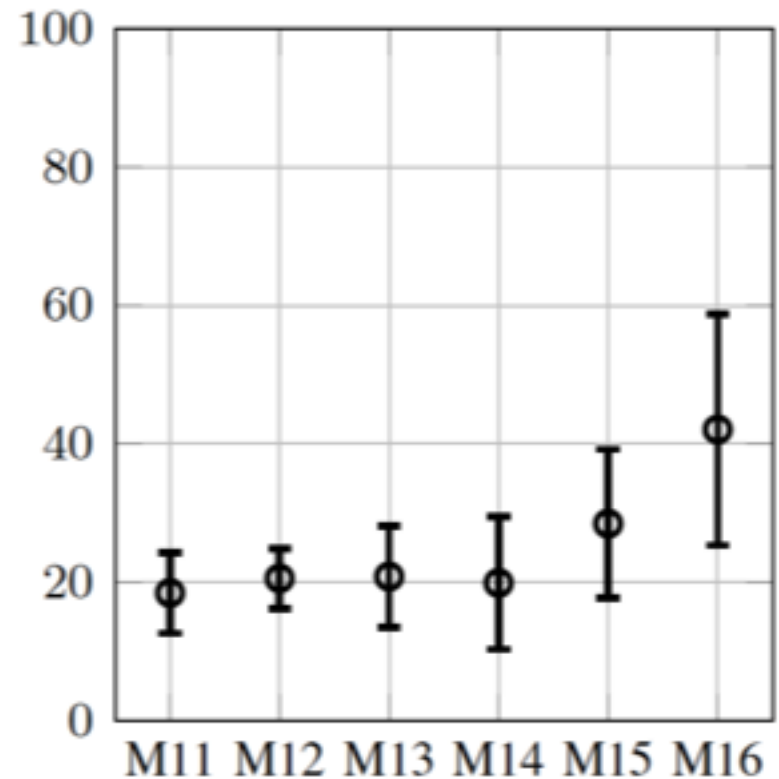
Increasing false lateral specific force cues

Motion Rating Results Takeoff Task

Max tilt-coordination pitch rate, deg/s



False motion cue rating, %



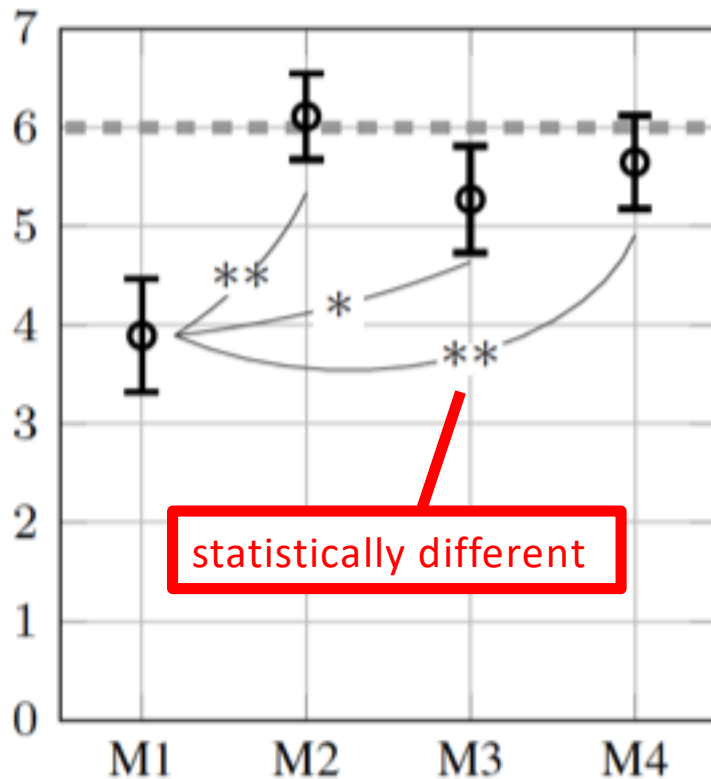
Increasing false pitch rate cues

Results

Objective Motion Cueing Criteria

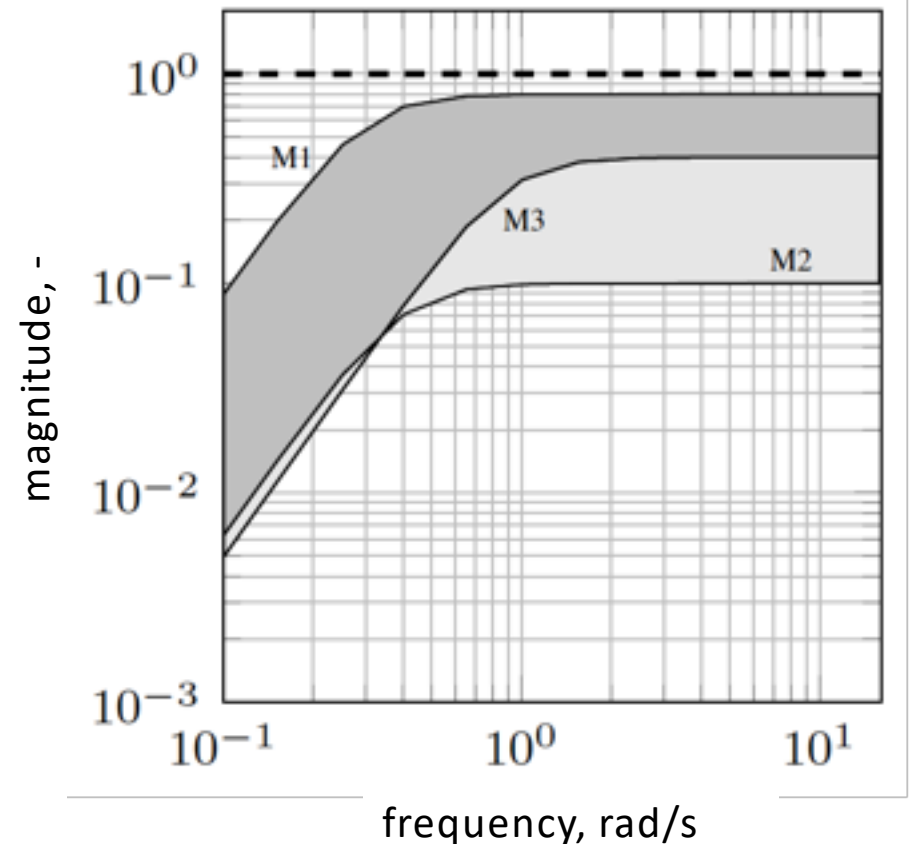
Step 1:

Touchdown sinkrate, ft/s



Step 2:

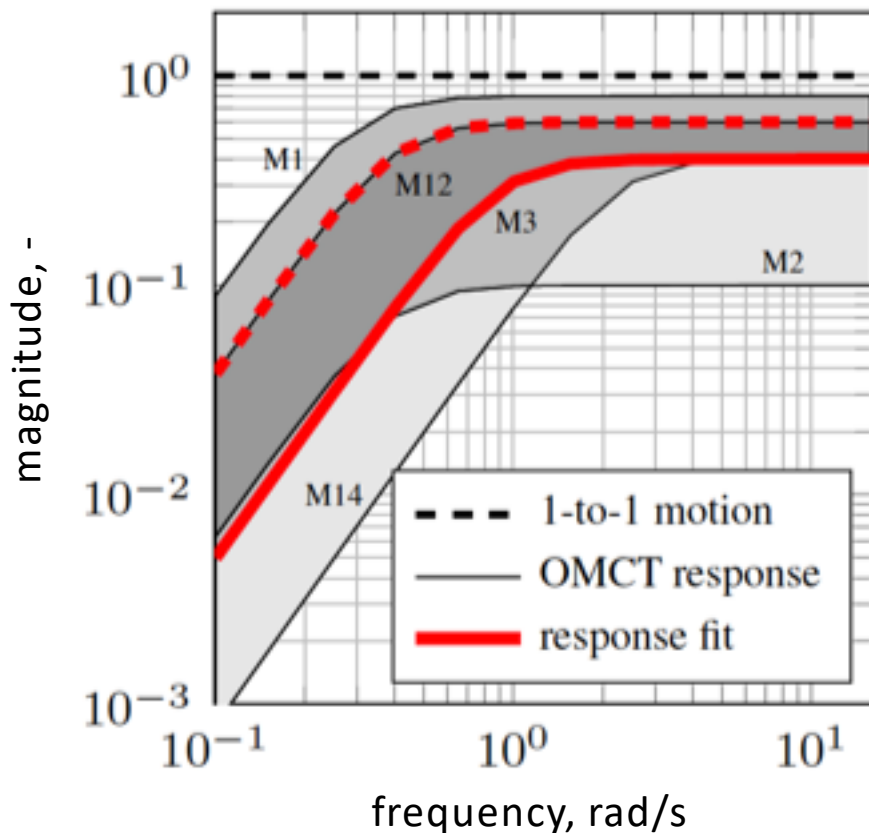
Heave uncertainty bounds



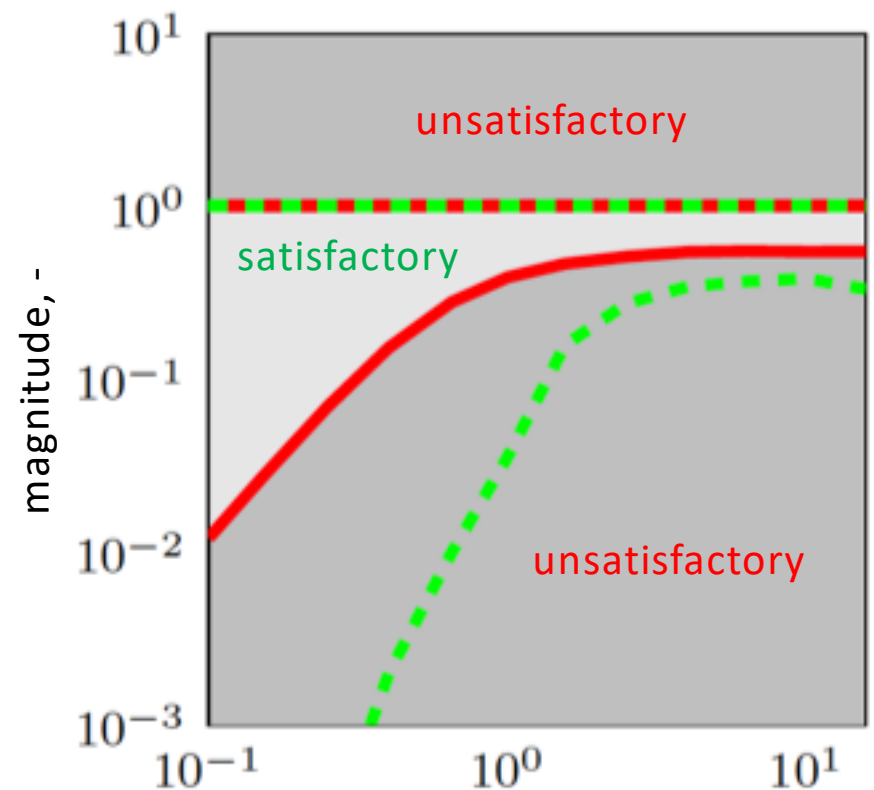
Results

Objective Motion Cueing Criteria

Step 3:
Heave response fit



Step 4:
Heave fidelity region

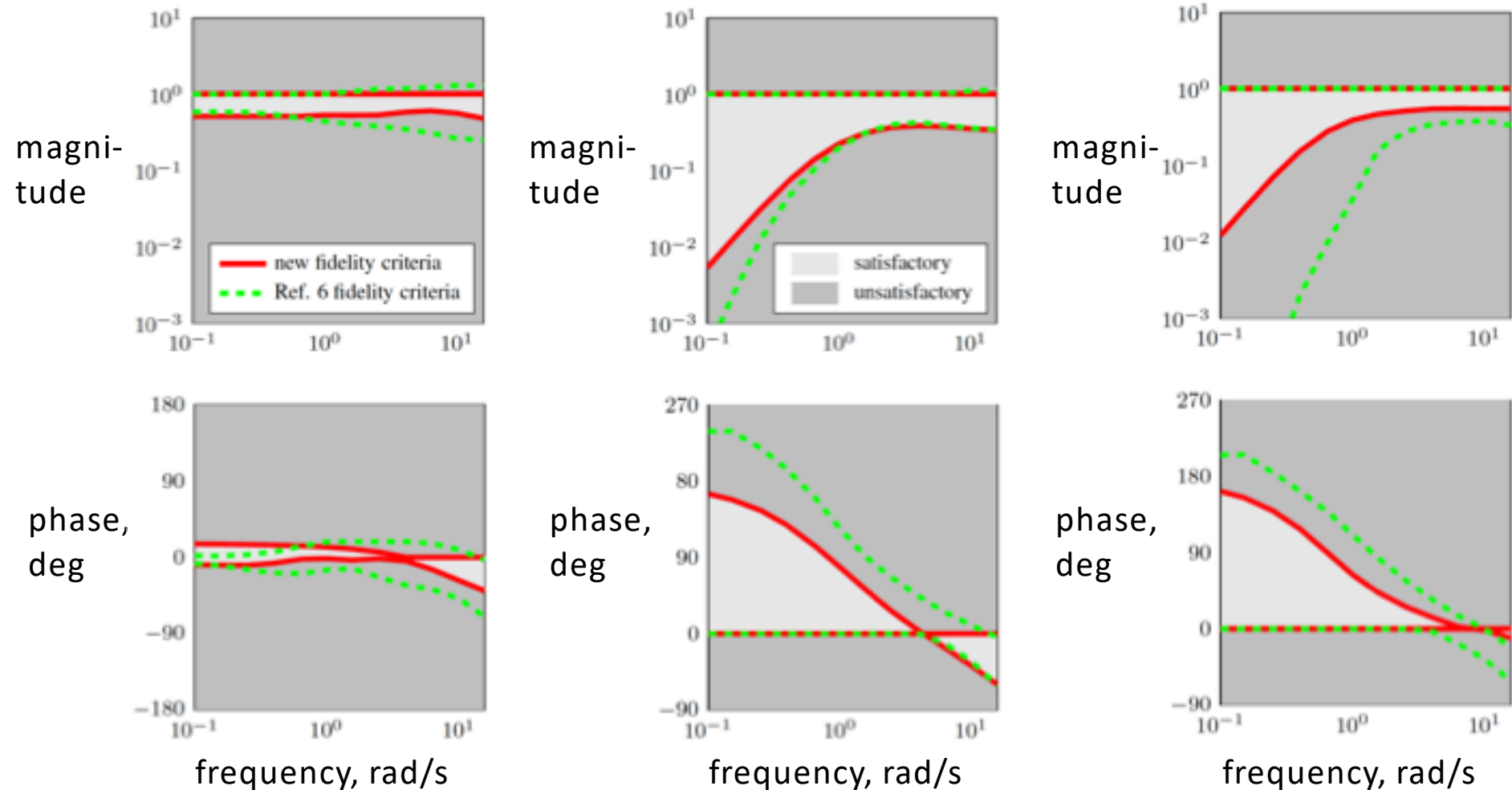


Rotational Motion Cueing Bounds

Pitch

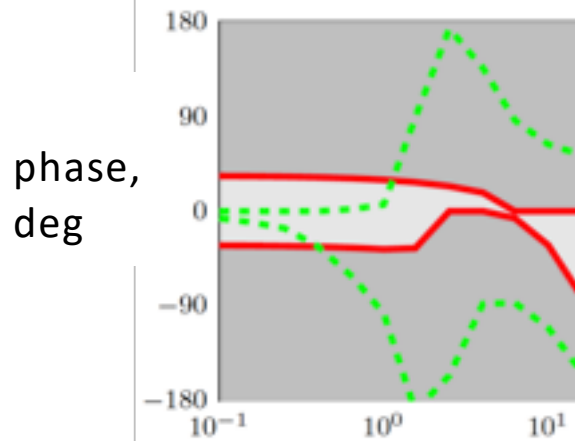
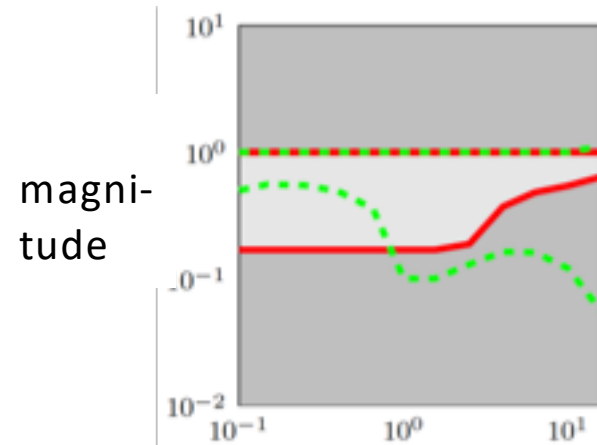
Roll

Yaw



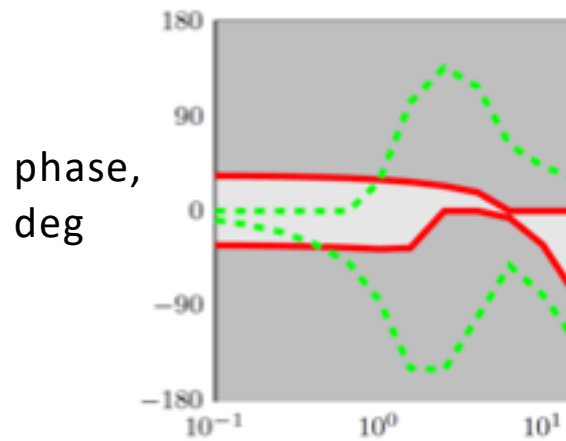
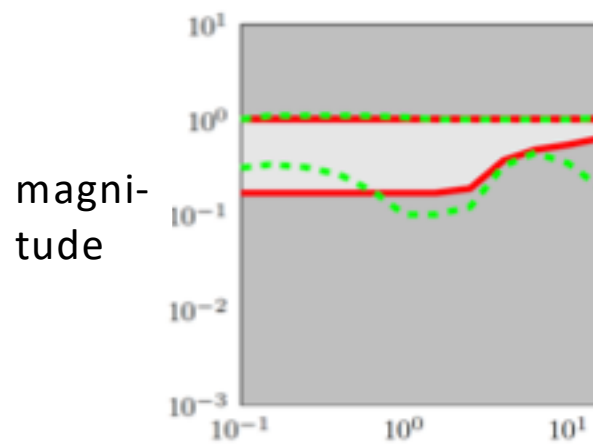
Translational Motion Cueing Bounds

Surge



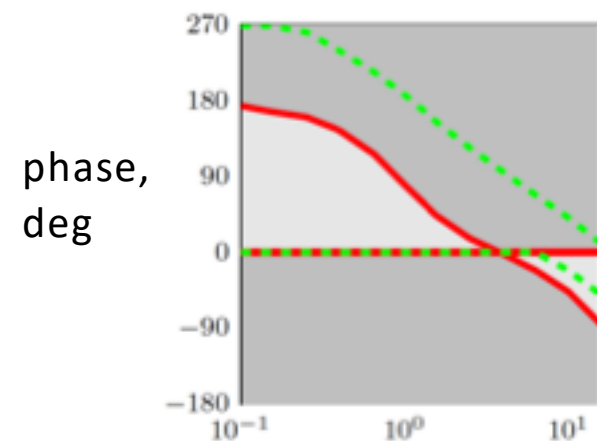
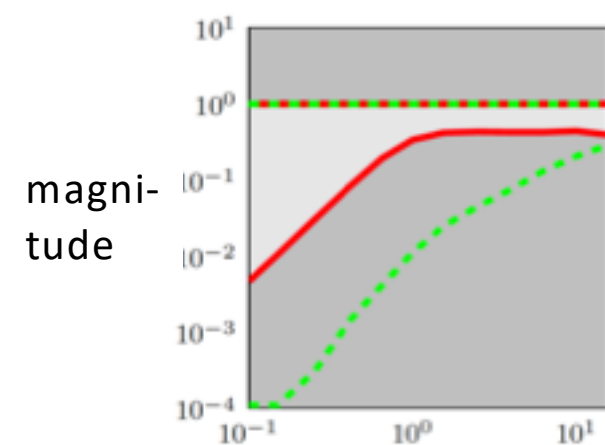
frequency, rad/s

Sway



frequency, rad/s

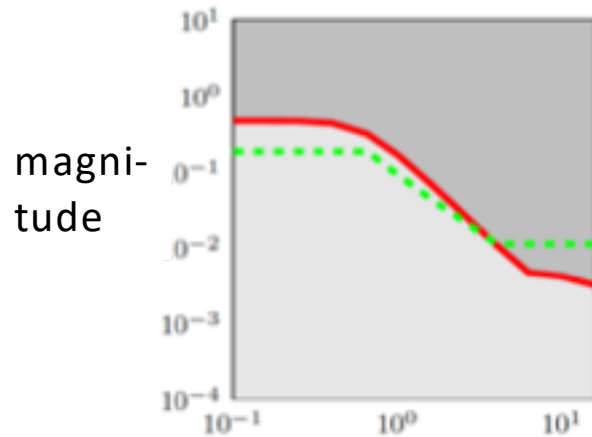
Heave



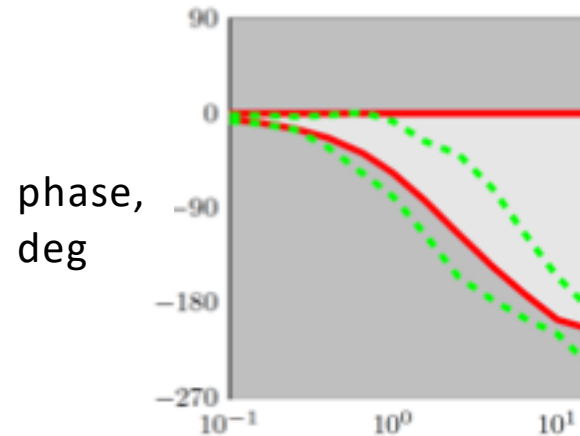
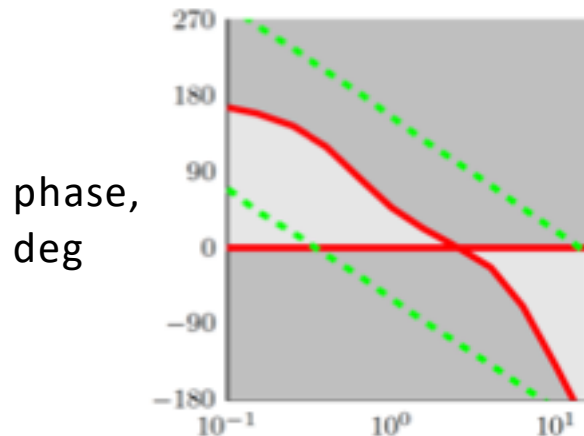
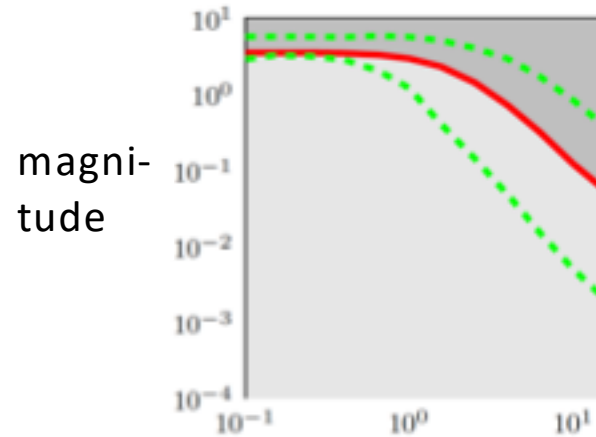
frequency, rad/s

Cross-Coupling Bounds

Roll to sway



Surge to pitch



frequency, rad/s

frequency, rad/s

Conclusions

1. Motion condition significantly affected:
 - Sinkrate at touchdown in the landing
 - Roll deviation in the stall approach
 - Maximum pitch rate in the stall recovery
 - Heading deviation after the engine failure
 - Pedal reaction time after the engine failure
2. False motion cues above the perceptual threshold resulted in higher false motion cue ratings in all tasks

Conclusions

3. Significant differences between motion configurations defined initial objective motion cueing criteria
4. Initial comparison against data from one simulator manufacturer shows promise. Translational motion fidelity would need improvement

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